DEPARTMENT OF THE AIR FORCE
AIR FORCE CIVIL ENGINEER CENTER

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Subject: Response to WAFB – ADEQ Comments – ST012 – Discussion toward Extending Steam Enhanced Extraction, Bioremediation (EBR) Transition, Former Williams Air Force Based, Mesa, Arizona.

Thank you for your letter of 11 February 2016 concerning the discussion of the steam enhanced extraction (SEE) transition to enhanced bioremediation (EBR) at the Former Fuel Storage Area (ST012) at the former Williams Air Force Base. The Air Force (AF) has prepared this response to comments received, although ongoing discussions on this topic have occurred during the February and April BRAC Cleanup Team (BCT) calls and the March BCT meeting. The status of ST012 transition issues was also summarized in the AF's letter to the EPA and ADEQ dated 29 March 2016 (in response to EPA and ADEQ letter of 7 March 2016).

The ADEQ comments from the 11 February 2016 are repeated below followed by responses in italics.

General Statement

ADEQ's position has not changed from that stated in the General Comment provided in the letter of November 19, 2015 (FPU16-109) to the Air Force, and is restated herein:

"The criteria for transitioning from SEE to EBR are provided in Table 4-2 of the May 2014 Work Plan. Two primary criteria are diminishing mass extraction rates (less than 10% of peak rates during SEE) and benzene groundwater concentrations less than 500 µg/L. To date, neither of these criteria have been demonstrated nor have indications of achieving these criteria in the near future. Mass removal rates are discussed in the Specific Comments [*FPU16-109*] and insufficient data have been provided regarding benzene concentrations. Until further progress is demonstrated, discussion of transitioning to EBR is premature."

Response: The Remedial Design and Remedial Action Work Plan (RD/RAWP) identifies temperatures and mass removal to be the two primary criteria. The Air Force is continuing to implement the ST012 remedy in accordance with the Operable Unit 2 (OU-2) Record of Decision Amendment 2 (RODA2) and RD/RAWP. On the basis of information previously presented in BCT *meetings, conference calls and in response to prior comments, the ST012 remedy is transitioning to EBR. The primary goal at this time is to collect information on the post-steam site conditions at ST012 so that implementation of EBR can be optimized. The Air Force will continue to implement the remedy to achieve the OU-2 RODA2 cleanup levels and estimated remedial timeframe.*

Specific EBR Transition Criteria

Subsurface Temperature

Temperatures are no longer a topic of discussion for ADEQ regarding transition to EBR. Subsurface temperature is an indirect remediation measure and has been extensively discussed.

Response: Subsurface temperatures are an indirect measure. Temperature measurements from both temperature monitoring points and calculated formation temperatures at MPE wells both indicate that steam temperatures have been reached where expected.

Completion of Pressure Cycling

ADEQ does not consider pressure cycling a viable metric for transitioning to EBR. Pressure cycling has not improved mass removal of volatiles at ST012 during SEE based on the data presented (e.g., Slide 21 of the January 2016 Base Closure Team (BCT) ST012 presentation). While pressure cycling to improve the recovery of volatile contaminants dissolved in water has been demonstrated at other sites and has a firm scientific basis, the same cannot be said for volatile compounds dissolved in a multicomponent Non-Aqueous Phase Liquid (NAPL) dominated by heavier hydrocarbons. The lack of improved mass recovery in the vapor phase during pressure cycling suggests benzene mass remaining in the Thermal Treatment Zone (TTZ) is primarily dissolved in residual NAPL rather than dissolved in water. Benzene dissolved in residual NAPL is not treatable by EBR until it is dissolved into surrounding water.

Response: Pressure cycling was identified in the RD/RAWP as a transition metric. Pressure cycling has been demonstrated to enhance mass removal after steam breakthrough was demonstrated. Volatilization is one mechanism for enhancement by pressure cycling but not the only mechanism:

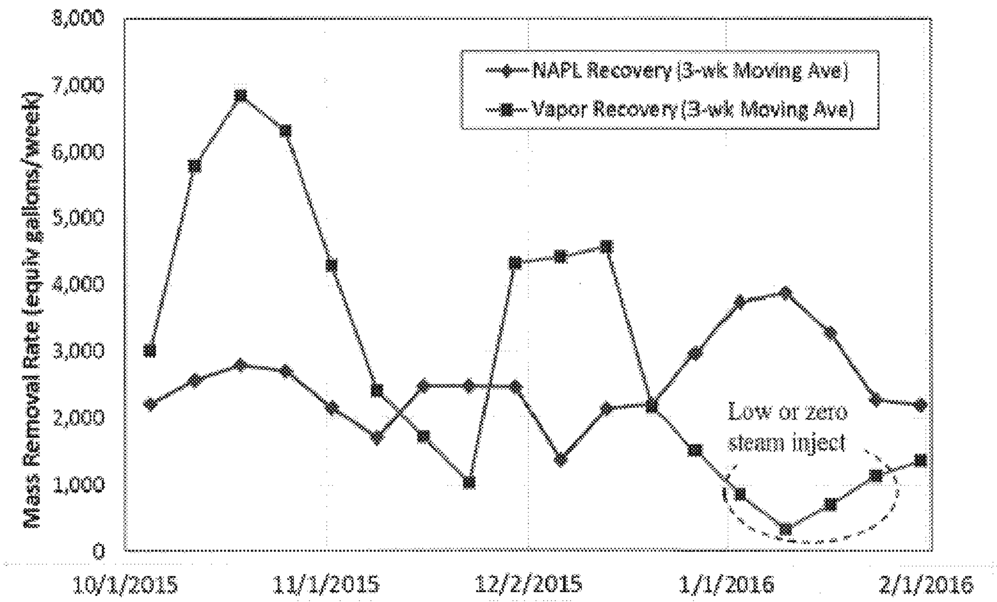
"For sites contaminated with semi-volatile or non-volatile chemicals, such as creosote, pressure cycling is used both to enhance vaporization of the lighter fractions of contaminants, and to induce mixing of injected steam and air with the contaminated groundwater. This may stimulate both dissolution of NAPL phases into the groundwater, and degradation reactions that take place under aerobic condition at elevated temperatures (HPO or biological degradation)." (USACE, 2009)

Lack of improved mass recovery in the vapor phase during pressure cycling more likely suggests that the perimeter contribution is greater than and hides the contribution from the TTZ interior. Benzene depletion from the NAPL by dissolution into the groundwater is the primary *pathway that forms the basis of the EBR design; however, there is some basis that degradation can occur in the NAPL (ITRC, 2009):*

"Although it is commonly assumed that biodegradation or mineralization of source zone constituent mass is limited by the rate of partitioning from the LNAPL to aqueous phase, several laboratory studies have shown that rates of mineralization of target constituents dissolved into solvents (NAPLs) have exceeded the measured rates of partitioning."

Mass Removal

ADEQ asserts the mass removal criteria for transition to EBR has not been achieved. Data from weekly progress reports were plotted to show the average gallons of NAPL recovered each week starting in October 2015. Equivalent gallons of NAPL recovered in the vapor phase were also plotted and the results are illustrated below. The NAPL recovery rate (red) has not decayed over the last four months, consistently averages over 2,000 gallons per week, and no indication of decay is evident. The vapor recovery rate (blue) illustrates a general decay; however, the rate dropped when the steam injection was lowered and ceased at the beginning of January. This drop in vapor recovery with steam cessation indicates significant mass continues to be recovered from within the TTZ by steam injection and that mass recovery rates continue to be related to steam injection.



As stated in the Work Plan, the actual site specific removal rate curve will be evaluated to confirm or adjust the appropriateness of 10% of maximum to represent a condition of diminishing returns. The plan further states, continued operation below the 10 percent of peak removal rate may be implemented depending on the significance of continued mass removal, the status of Contaminant of Concern (COC) concentrations (e.g., benzene) in extracted fluids, and the need/ability for EBR to achieve further degradation based on data collected during the EBR field test.

Response: The mass removal data as presented in the weekly reports can create confusion for this type of analysis. Vapor mass removal includes both wellfield vapor mass as well as volatilized contamination from liquid treatment systems (tank vents and air stripper off gas). The turbulent flow encountered in the extraction system may also promote contaminant phase changes between the extraction wells and the treatment system. Vapor mass removal from the weekly reports can be affected by the latest available laboratory data. Vapor mass removal rates are calculated in the weekly reports based on the most recent available laboratory data. When new data is received, vapor mass removal calculations are adjusted back to the sample date but mass removal totals in previous weekly reports are not corrected and reissued. Finally, NAPL removal in the weekly reports is based on the total NAPL transferred to the storage tanks during the week divided by seven days. When NAPL is apportioned equally between days since the previous transfer it results in a slightly different NAPL removal rate.

These combined factors introduce errors using the data from the weekly reports in as described in the comment. The information presented in the BCT calls and meetings are a better representation of mass removal for making the type of evaluations described in this comment. The actual mass removal calculation spreadsheet has been provided (email from Don Smallbeck to BCT members on 4 March 2016) with data and mass removal calculations through the end of February.

With respect to the consistency of mass removal over several months, the adjustments made to continue to improve mass removal have likely contributed to the slow overall change in mass removal rates. Also, pressure cycles prior to the January depressurization were not coordinated across all three zones simultaneously, which may have hidden some of the mass removal fluctuations during earlier pressure cycles.

The Air Force has not presented any assessment of the appropriateness of the 10% value for diminishing returns and in particular a value comparison of mass removal rates during SEE with those anticipated for EBR. For example, a total hydrocarbon rate of 1,400 pounds per day entering the thermal accelerator for destruction can be viewed as the equivalent of injecting 1.5 tons of sodium sulfate per day under perfect conditions. This calculation assumes complete sulfate utilization and only 30% of the extracted hydrocarbon mass would be available in the subsurface (assumptions in EBR Work Plan Addendum). A NAPL recovery rate of 300 gallons per day is equivalent to the injection and utilization of 2 tons of sodium sulfate per day under the assumptions of the Work Plan Addendum and assuming the NAPL components dissolve into water that then mixes with the sulfate solution to yield complete utilization by contaminants.

Response: The AF letter of 29 March 2016 provides an overall assessment of the status toward meeting the transition criteria, including the effect of perimeter contributions on mass removal, benzene concentration transition targets, and the EBR design. Removal rates for EBR will be less than they are currently with SEE; however, economics and sustainability favor a transition to EBR.

It is the opinion that mass removal should not be divided, or a distinction made, between mass within the treatment zone and mass outside the treatment zone. The process should continue as long as mass is removed. The Record of Decision (ROD) does not distinguish between the within/without TTZ boundary.

Response: The ROD states, "When the effectiveness of the contaminant mass removal by SEE has diminished, the remedial action will transition to enhanced bioremediation. The criteria that will be evaluated for this transition will be developed jointly by the AF, EPA, and ADEQ as part of the Remedial Design/Remedial Action Work Plan." The ROD recognizes that the remedy at ST012 is a multi-technology approach and defers the transition criteria to the RD/RAWP. The RD/RAWP distinguishes between the within/without TTZ boundary and identifies potential mass contributions from outside of the TTZs as a factor to be considered when evaluating the transition criteria. SEE becomes less efficient and less sustainable as mass removal decreases. Further mass removal continued during the post steam extraction phase.

It is the opinion that SEE should continue until the NAPL outside the TTZ is removed. It is the opinion that expanding the steam system is viable.

Response: The SEE system cannot be expected to remove all NAPL outside the TTZ as it was not designed for this approach. Expansion of the steam system is not viable while the system is operating or the site is at elevated temperatures. The Air Force is now focused on gathering information on post-steam site conditions so that EBR implementation can be optimized towards the objective of achieving OU-2 RODA2 cleanup levels in the estimated remedial timeframe.

It is the opinion that it is not demonstrated that the sulfate injection can degrade LNAPL to meet remedial action objectives (RAOs) by 2032.

Response: The demonstration of the concept was presented in the RD/RAWP and discussed further in the March 2016 BCT meeting, as well as in the 29 March 2016 letter from the AF to EPA and ADEQ. Post-steam site conditions need to be established and EBR implemented in order to appropriately evaluate remedy progression and potential activities necessary for achieving the benzene cleanup level.

It is the opinion that EBR has not been demonstrated to be appropriate to treat NAPL, only dissolved phase. The ROD does not state that EBR will be employed to treat NAPL.

Response: EBR mechanisms work directly in the dissolved phase and address NAPL indirectly by promoting the dissolution of COCs from NAPL. The OU-2 RODA2 groundwater remedy is directed primarily at achieving benzene cleanup levels in the dissolved phase. The distribution of benzene exceeding cleanup levels at ST012 have been within or immediately adjacent to the footprint of the TTZs in recent years (see Annual Groundwater Monitoring Reports). It is expected that the significant removal of LNAPL from the TTZ and immediately adjacent perimeter areas during steam enhanced extraction will have a significant impact on the post-SEE benzene mass within and immediately adjacent to the TTZs where groundwater impacts have historically been observed. Therefore, the Air Force considers it crucial to gather information on post-steam site conditions both to assess the degree of SEE success as well as to optimize EBR implementation. The Air Force is continuing to implement the RD/RAWP towards the objective of achieving the OU-2 RODA2 cleanup levels.

Benzene Concentrations

ADEQ asserts the benzene concentration criteria for transition to EBR has not been achieved. As stated in the Work Plan, benzene concentrations in extracted groundwater are monitored for transition to EBR against a target benzene concentration in the 100 to 500 microgram per liter (μg/L) range within the TTZ. The most reliable measure of benzene concentrations in extracted groundwater is provided at the air stripper inlet. These concentrations are decaying (Slide 29 of the January BCT ST012 presentation) but remain well above 500 μg/L and well above the value measured when steam injection was initiated. At a minimum, this measure of benzene concentration should fall below its initial value to indicate a significant overall depletion of benzene from the TTZ even if the benzene from the perimeter is contributing to the extraction. Such decay has not been achieved indicating heat from steam injection continues to enhance benzene extraction.

Response: Air stripper influent is a reliable measure of benzene concentration progress. Because some heating has occurred outside the TTZ, perimeter concentrations may contribute higher concentration than initial values. Samples during pressurization approached initial values. The target benzene concentration of 100 to 500 μg/L as stated in the RD/RAWP is the range predicted to achieve cleanup levels within the 20-year remedial timeframe based on modeling of groundwater contaminant attenuation outside the TTZs after active EBR. This target was used for areas within the TTZ but it was also acknowledged in the RD/RAWP that perimeter contributions may mask benzene removal within the TTZ. There is evidence that perimeter groundwater from outside the TTZ is contributing to concentrations in the air stripper influent above this range. With EBR modeling, benzene concentrations as high as 5,500 μg/L were anticipated.

Benzene located around the perimeter of the TTZ and the perimeter/interior extraction wells contribute to the benzene in the extracted groundwater. If the interior is "clean" compared to the perimeter, the mass removal rate should increase with the cessation of steam injection as extraction from the perimeter increases. However, as described above, the opposite was observed indicating significant mass remains in the TTZ.

Response: This conclusion is confusing because the LNAPL removal rate did increase during the last depressurization following cessation of steam. As noted previously, vapor mass removal from the weekly reports can be affected by several factors. Daily estimated vapor mass removal rates as presented in the BCT calls/meetings show an increasing rate during the January depressurization event.

Calculated benzene concentrations in individual extraction wells were presented in Slides 32-34 of the January BCT ST012 presentation. These values are not measured directly but are calculated with significant uncertainties using a mass balance. In addition, these measures were performed when approximately half of the extracted water originated through clean water injection (i.e., steam injection) potentially diluting the extracted water. Pathways of water flow during SEE are not representative of ambient groundwater flow or resulting benzene concentrations post-SEE.

Response: Measurement of benzene concentration in groundwater during injection is most representative of progress inside the TTZ because:

- *Contribution from outside the TTZ is reduced*
- *Contamination remaining inside the TTZ is transferred to the clean water (i.e., steam injection) as it travels from injection to extraction wells. Even if 100% of sampled water originated as steam, low concentrations in extracted water indicate diminished remaining mass in the TTZ*

Measurement of benzene concentration in groundwater during depressurization is less representative of progress inside the TTZ because:

- *Contribution from outside the TTZ is increased*
- *Volatilization may decrease water concentration during early phases of depressurization*

Steam Injection

ADEQ asserts that reaching the steam injection quantity guideline is not a basis for transitioning to EBR. As stated in the Work Plan, the actual steam required to achieve the other criteria may be more or less than originally estimated. Because this parameter does not directly measure remediation performance its primary use is to assess the estimate in the design. As a result, ADEQ does not consider attaining the design steam injection target criteria of 319,357,000 pounds to be a metric for transitioning to EBR.

Response: Concur that this metric is a guideline for comparison as described in the RD/RAWP.

Please contact me at (315) 356-0810, ext. 204 or catherine.jerrard@us.af.mil if you have any questions regarding this response to comments.

Sincerely,

CATHERINE JERRARD
BRAC Environmental Coordinator

References:

Interstate Technology Regulatory Council (ITRC), 2009, Evaluating Natural Source Zone Depletion at Sites with LNAPL, April, 2009.

US Army Corps of Engineers (USACE), 2009. Design: In Situ Thermal Remediation. EM-1110-1-4015. 28 August 2009

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